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EV Battery Management System with Charge Monitoring

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Abstract- This project presents an innovative Battery Management System (BMS) for electric vehicles, leveraging Arduino UNO to ensure optimal battery performance, safety, and longevity. The system is designed to monitor critical parameters such as voltage, current, temperature, and state of charge (SOC), while also assessing the state of health (SOH) of the battery. The BMS supports both fast and slow charging modes, intelligently managing charging processes to prevent overcharging and thermal runaway. User-friendly interfaces, including real-time data displays, offer intuitive insights into battery status, empowering users with actionable information. This project combines cost-effective hardware with comprehensive safety and performance monitoring, making it a significant step toward safer and more efficient electric vehicle batteries. Real-time SOC/SOH evaluation, and versatile charging management, which collectively advance the capabilities of conventional battery management solutions.

Keywords – Battery Management System (BMS), Electric Vehicles (EV), Arduino UNO, State of Charge (SOC), State of Health (SOH), Voltage Monitoring, Current Sensing.

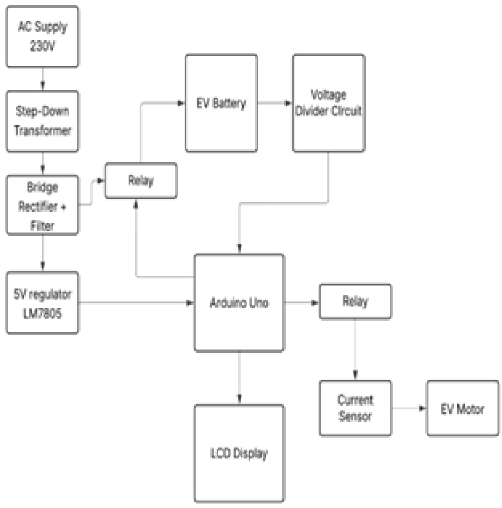
I. INTRODUCTION

The rapid pace of EV adoption indicates a pivotal shift toward sustainable and eco-friendly transportation solutions, driven by concerns over climate change, depletion of fossil fuels, and strict global emission regulations. As EV technology continues to evolve, the major challenges yet to be overcome are reliability and safety concerns with energy storage-that is, predominantly lithium-ion batteries-to gain wide acceptance and large-scale deployment by users. Intrinsically, lithium-ion batteries are prone to aging, overheating, and thermal runaway, which may lead to early degradation of performance and unsafe operating conditions, even catastrophes. In this regard, continuous monitoring, safe charging, precision balancing, and comprehensive protection mechanisms have now become key elements in enhancing overall dependability in EVs.

These issues have motivated the development of an advanced EV-BMS with integrated sensing, control, and protection in a unified architecture. Current, voltage, and temperature sensors are interfaced with an Arduino-based microcontroller for the real-time monitoring of critical battery parameters. Information obtained from sensors is passed through intelligent decision-making algorithms to assess the SOC, SOH, and level of stress on the battery. Whenever the BMS detects any abnormal operating condition, such as overvoltage, undervoltage, overcurrent, deep discharge, or excessive thermal buildup, it initiates an automatic safety cut-off to isolate the main battery pack from the powertrain or charger to prevent irreversible damage and ensure user safety.

Beyond conventional protection strategies, the architecture includes a specific fire protection and thermal management subsystem for thermal runaway mitigation. This subsystem continuously interprets temperature profiles of the battery pack and triggers preventive actions such as forced cooling through fan activation, dynamic current limitation during charging or discharging, and emergency shutdown in extreme thermal abnormalities.

II. WORKING PRINCIPLE



1. Power Input and Conversion Stage

i. AC Input Supply

A standard AC mains supply initiates the system for providing the input power required to charge the battery. Since the raw AC supply cannot be used directly for charging the battery, first of all, it needs to be stepped down and rectified into a DC form that can be used. This AC input provides the primary energy source for the whole charging system.

ii. Operation of a Step-Down Transformer

The AC supply is first passed through a step-down transformer. The transformer steps down the high AC voltage from mains to a low-level voltage suitable for rectification and regulated DC charging. The transformer provides isolation from mains for safeguarding the system against high-voltage fluctuations. This stage ensures safe and controlled handling of electrical energy before it reaches the battery.

iii. Rectification and Filtering

The transformer's output is AC, incompatible with the DC-operated circuits, such as a microcontroller and a battery. The AC output from the transformer feeds into a bridge rectifier, which converts the alternating waveform into a pulsating DC signal. This pulsating DC is further smoothed through filter capacitors to reduce ripple and produce a stable DC voltage. Filtering is critical to avoid noise, instability, and possible damage to sensitive electronics.

iv. Voltage Regulation for Control Electronics

Once the DC voltage is stabilized, it is fed through a voltage regulator to obtain a fixed low voltage that will be safe for the Arduino microcontroller and other low-power devices. In the case of a linear voltage regulator, it maintains the same voltage in the control circuit when the input supply varies. This regulated DC now acts as the supply for the Arduino, sensors, display module, and the relay coils themselves.

2. Battery Sensing And Monitoring Stage

i. EV Battery Connection

The EV battery under monitoring is connected to the BMS. A battery serves as both the energy storage unit and the main parameter that a system needs to supervise. During charging, this battery receives DC power from the charger through controlled switches. During discharging, it supplies power to the motor or other loads. All the monitoring operations are done while ensuring long-term health of the battery.

ii. Voltage Sensing using Voltage Divider

Since the voltage coming from the battery may be larger than the input voltage that the microcontroller ADC can directly handle, a voltage divider circuit is used in order to scale down the amplitude of the battery voltage to a safe-measurement level. The divided voltage is fed to the Arduino for continuous monitoring of the battery's voltage level. This helps the BMS determine charge state, detect overvoltage, undervoltage, and ensure safe operation during charging and discharging.

iii. Current Sensing for Charge/Discharge Monitoring

A current sensor in series with the battery and the load detects the flow of current during both battery charging and during the operation of the load. This sensor outputs a voltage signal proportional to current. Arduino interprets this signal to understand whether the battery is charging, or discharging, and how much current is flowing. Monitoring current is very essential for safety functions, such as over-current protection, short-circuit detection, and estimating the battery's State of Charge (SoC).

3. Control Unit

i. Data Acquisition by Arduino

The Arduino Uno acts as the brain of the whole system. It constantly reads analog signals from both the voltage divider and the current sensor, along with temperature or other sensor inputs if included. These sensor readings are updated periodically so that the Arduino will have real-time information about the state of the battery.

ii. Signal Processing and Interpretation

After the Arduino gets sensor readings, it processes the data. It converts raw analog signals into meaningful voltage and current levels. The microcontroller will apply filtering, threshold checking, and decision logic. Based on voltage levels, the Arduino can estimate whether the battery is depleted, partially charged, or nearing full charge. Based on current flow, it can determine whether the system is in charging mode or discharging mode.

iii. State of Charge (SoC) Monitoring

The BMS keeps an ongoing estimate of the State of Charge (SoC) of the battery. It examines voltage trends, current direction, and historical charge-discharge patterns. The microcontroller constantly updates the estimated percentage of charge available in the battery. This SoC value informs the user how much energy is left and when the battery will need recharging.

4. Charging Control and Protection Stage

i. Activation of Rela

The relay that controls the charging line is driven by the Arduino. Once the Arduino decides it is safe to charge the battery, it turns on the relay and allows power to flow to the battery. If the voltage of the battery is too low or if the system detects unsafe conditions, the relay stays off and prohibits charging.

ii. Overvoltage and Undervoltage Protection

The BMS continuously monitors if the voltage of the battery exceeds the safety threshold limits. If the voltage exceeds the maximum allowable threshold, the microcontroller instantly switches off the relay to stop charging. Similarly, if the voltage of the battery falls below the minimum safe limit during operation with load, the system disconnects the motor load as a means of protection against deep discharge of the battery.

iii. Overcurrent and Short-Circuit Protection

The Arduino is designed to disable the relay automatically when the current sensor detects abnormal or excess current flow during charging or motor operation. This will prevent overheating and further damage to the battery, besides protecting the EV motor. Overcurrent detection is a critical aspect of charging safety and user protection.

iv. Temperature Monitoring and Thermal Safety

If integrated, the temperature sensor monitors the thermal condition of the battery. Heating is normal during fast charging or high current load. The BMS does continuous monitoring of temperature and disables charging or load supply if the temperature exceeds limits for safe operation.

.5. Display And User Interface Stage

i. LCD Display Updates

It displays all the essential parameters, like battery voltage, current, and State of Charge on an LCD module. The user gets immediate feedback on the status of the battery. The display may show charging mode, discharging mode, faults, and percentage charge. This makes the operators fully aware of the condition of the EV battery at all times.

ii. Status Indication and Alerts

1. A system like this might include indicators, LEDs, or buzzers.
2. Green light means normal charging
3. Red light indicates a fault
4. Yellow-light indication means low battery or in standby.
5. These user-friendly indicators help to promptly identify the states of operation without necessarily accessing the LCD.

6. Load (Motor) Control And Discharge Monitoring Stage

i. Relay for Motor Switching

Another relay is for the control of an EV motor or load. Arduino enables this relay only when the battery has a safe amount of charge and no fault is detected. When the voltage of the battery drops too low, the motor relay is switched off to prevent damage due to deep discharge.

ii. Continuous Discharge Monitoring

Here, the BMS monitors the discharge current, battery voltage drop, and temperature rise during a load operation. The microcontroller ensures that the motor will not draw too much current. It also ensures that during high current load conditions, the voltage level of the battery does not reach unsafe levels.

7. Protection Logic And Fault Handling Stage

i. Real-Time Fault Detection

The BMS continuously compares the measured parameters against predefined limits of safety. Any deviation from these is immediately highlighted. Common faults include:

- Overvoltage while charging
- Undervoltage during discharging
- Overcurrent

Temperature increase Reverse polarity Sensor faults Once detected, the BMS shifts into fault protection mode.

ii. Automatic Isolation of Battery

The BMS opens the relay or contactor and protects the battery in case of a fault condition. This disconnects the battery from the charger or motor, preventing further damage. Safety of the system remains the highest priority. Step 21: Safe Shutdown and Warning Alerts After disconnecting the battery, the system will send an alert to the user via the LCD or buzzer. This will make sure that the operator recognizes the unsafe condition and performs an action in response.

III. SYSTEM DEVELOPMENT

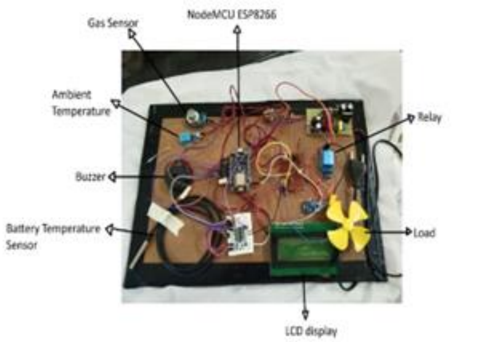


Fig.1.EV Battery management system with charge monitoring

The Electric Vehicle Battery Management System (EV-BMS) uses an Arduino microcontroller with it contains sensors to monitor voltage, current, and temperature in real time. It then calculates SOC and SOH to maintain balanced charging and prevent damage. Safety during faults is ensured by protection together with thermal management. The all operations are controlled by Arduino, enhancing battery efficiency, safety, and life. The proposed EV-BMS ensures safe charging through systematic hardware and software integration.

Optimum energy management and extension of the battery lifetime, the developed system enhances not only the user. It provides safety and confidence but also contributes to sustainable and efficient electric vehicle technology. The software development phase involves coding in Arduino IDE to execute data acquisition, fault. Detection and automatic control operations. The algorithm calculates SOC, SOH, and temperature variations, with efficient energy utilization. For extended functionality, IoT-based data logging and remote monitoring can be integrated to record system parameters and provide real-time insights for Maintenance and diagnostics.

- The objective of Electric Vehicle Battery Management System development is to provide an intelligent battery management system.
- Reliable, safe, and intelligent platform for monitoring and controlling the performance of lithium-ion batteries.
- Used in electric vehicles. The system is designed around an Arduino-based microcontroller, which acts as
- The central control unit, interfacing with various sensors and protection circuits.

Hardware architecture design represents the first stage in development, which includes:

Voltage, current, and temperature sensors to make continuous measurements of key battery parameters. These sensors provide real-time
feedback to the microcontroller, which processes the data to determine the State of SOC and SOH of the battery pack. Based on these values, the system makes sure that balanced charging and discharging of all cells, avoiding overcharging, deep discharging, and overheating. A relay-based protection is installed to automatically cut off the power supply. Supply during abnormal conditions such as overvoltage, undervoltage, overcurrent, or excessive temperature. This safety feature minimizes battery damage and may reduce possible incidents of fire. An additional fire detection and thermal management subsystem helps improve safety by initiating cooling fans or cut-off circuits when critical temperature levels are detected.

IV. RESULTS

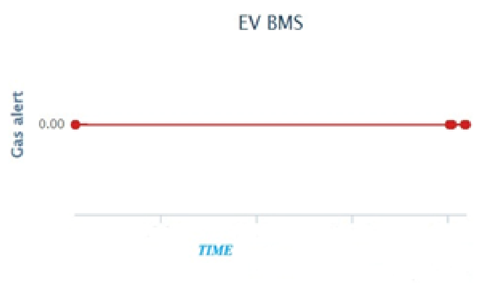


Fig:2 The gas sensor output stays at zero for the whole observation period, which means that there is no dangerous gas leak and that the conditions are safe for work.

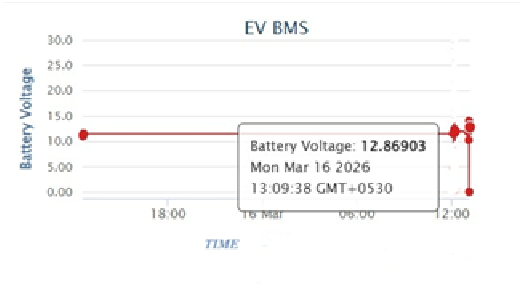


Fig:3 Under normal conditions, the battery voltage is about 12.8 V. However, there are occasional spikes and drops that could be caused by measurement noise or changes in the charging and discharging cycles.

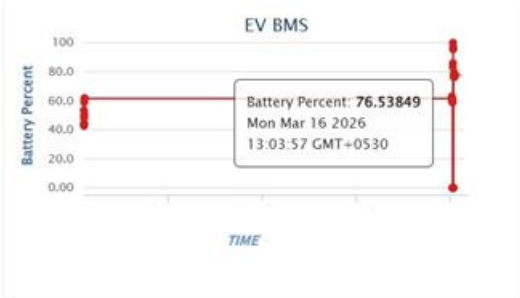


Fig.4 The battery percentage initially remains within a moderate range but exhibits abrupt fluctuations, indicating inaccuracies in SOC estimation or inconsistencies in sensor data acquisition.

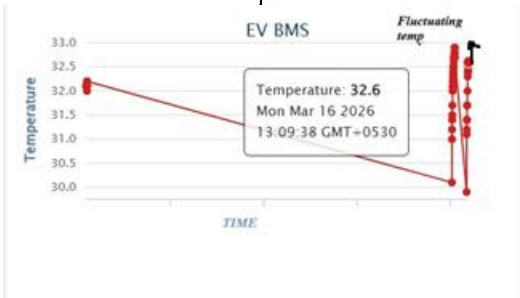


Fig.5 The battery temperature is maintained within a safe range (30–33°C) with minor variations, demonstrating stable thermal performance of the system.

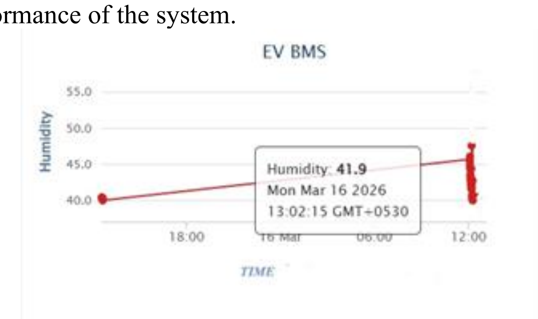


Fig.6 The humidity levels show moderate variation between 38% and 58%, reflecting environmental changes without posing significant impact on system performance.

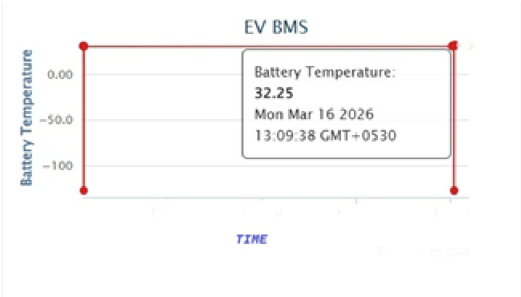


Fig.7 Time-series plot of EV battery temperature with red markers; a highlighted reading shows 32.25 °C

V. CONCLUSION

The designed BMS effectively monitors and manages the EV battery pack by ensuring safety and efficiency operation. The prototype successfully implements key features like voltage, current, and temperature. Monitoring, protection functions. This system can be expanded further to allow for real-time EV applications. The designed BMS plays a vital role in the effective operation of the monitoring and management of the EV battery pack for safety, efficiency, and reliability. Operation. Since the battery is the heart of the electric vehicle, it is of prime importance to maintain its performance and safety. Utmost importance. This system continuously monitors critical parameters such as voltage, current, and temperature,

helping prevent overcharging, over-discharging, and overheating-all of which can considerably reduce the battery life or even result in hazardous conditions such as thermal runaway or fire.The implemented prototype uses an Arduino microcontroller to acquire and process sensor data in real time. Display the values on an LCD and take necessary control action through relays and alarms when abnormal conditions are detected.

The BMS design integrates many protection features, like automatic cutoff, using relays during fault conditions, audible warnings using a buzzer in case of over temperature or fire detection, and dynamic response to varying load or charging situations. The voltage and current sensors provide accurate measurement for determining the State of Charge (SOC) and State of Health (SOH), while temperature sensors ensure that the battery remains within its safe operating range. Together, these Components contribute to extending the battery's life, improving overall energy efficiency, and Ensuring the safety of both the system and its user.

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